Technical Report 12-007

Functional Network Analysis: A New Way to Compare Frontier and Emerging Markets

Margaret Moten
Daniel Evans

U.S. Military Academy, West Point NY

June 2012

United States Military Academy
Network Science Center

**U.S. Military Academy
Network Science Center**

Authorized and approved for distribution:

BG (R) CHRIS ARNEY, Ph.D.   COL JOHN M GRAHAM, Ph.D.
Network Science Chair   **Director, Network Science Center**

Technical review by

Csilla Szabo, Ph.D., Department of Mathematical Sciences, U.S. Military Academy
Brain Macdonald, Ph.D., Department of Mathematical Sciences, U.S. Military Academy

NOTICES

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
27-06-2012	Technical Report	June 2010–June 2012

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Functional Network Analysis: A New Way to Compare Frontier and Emerging Markets	n/a
	5b. GRANT NUMBER n/a
	5c. PROGRAM ELEMENT NUMBER n/a

6. AUTHOR(S)	5d. PROJECT NUMBER
Margaret Moten, Daniel Evans	ARO NetSci 02
	5e. TASK NUMBER n/a
	5f. WORK UNIT NUMBER n/a

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Network Science Center, U.S. Military Academy 601 Cullum Road, Thayer Hall Room 119 West Point, NY 10996	n/a

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
U.S.Army Research Office Triangle Park, NC	USMA NSC
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) 12-007

12. DISTRIBUTION / AVAILABILITY STATEMENT

Unlimited Distribution

13. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

14. ABSTRACT

The study of frontier capital markets provides a unique opportunity to examine the network-based intersection of human behavior and economics. The individual motivations, information availability, transaction systems, and cultural realities in these markets provide a rich context of study. A social network analysis reveals interesting insights about how interrelationships among actors and organizations affect market operations and development. Network analysis provides both a visual and mathematical representation of the relationships and information flows between people, organizations, and functions enabling us to describe capital market structure and function in innovative ways. This study involves developing methodologies to classify capital market networks by comparing the capital markets in three frontier markets (Ghana, Tanzania, and Trinidad and Tobago) to the capital market in an emerging market (the Czech Republic). The analysis highlighted similarities and differences among the markets in order to develop a quantitative capital market classification framework. This research provides insights to economists seeking to understand the interconnections between economic actors and their affects on financial markets and economic conditions.

15. SUBJECT TERMS
Social Network Analysis, Network Science, Economics, Capital Markets, Frontier Markets, Emerging Markets

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Tish Torgerson
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UL	23	**19b. TELEPHONE NUMBER** (include area code) 845-938-0804

Functional Network Analysis: A New Way to Compare Frontier and Emerging Markets

Margaret Moten
Daniel Evans

U.S. Military Academy, West Point NY

ACKNOWLEDGEMENT

June 2012

Functional Network Analysis:
A New Way to Compare Frontier and Emerging Markets
Margaret Moten and Daniel Evans

Abstract

The study of frontier capital markets provides a unique opportunity to examine the network-based intersection of human behavior and economics. The individual motivations, information availability, transaction systems, and cultural realities in these markets provide a rich context of study. A social network analysis reveals interesting insights about how interrelationships among actors and organizations affect market operations and development. Network analysis provides both a visual and mathematical representation of the relationships and information flows between people, organizations, and functions enabling us to describe capital market structure and function in innovative ways. This study involves developing methodologies to classify capital market networks by comparing the capital markets in three frontier markets (Ghana, Tanzania, and Trinidad and Tobago) to the capital market in an emerging market (the Czech Republic). The analysis highlighted similarities and differences among the markets in order to develop a quantitative capital market classification framework. This research provides insights to economists seeking to understand the interconnections between economic actors and their affects on financial markets and economic conditions.

Capital Markets and Development

Individuals make economic decisions in a market context that is influenced by their social interactions and opportunities. Examining the structure, dynamics, and unique characteristics of the capital market network in which they operate is vital to understanding how capital markets evolve. Especially in developing economies,

individuals make reciprocal exchanges and clan or family interests, social norms, and institutions are as important as individual self-interest. Thus, harnessing the personal, corporate, and information networks that underlie developing capital markets is a critical component for creating programs that expand economic opportunities.

Economic research has recognized that well-functioning financial markets are associated with economic growth.[1] However, little is understood about the individual and functional networks in capital markets in the world's less-developed countries. These capital markets, often termed frontier markets, are ones in which social connections play a much more critical role than in developed capital markets. Vibrant capital markets enable developing economies to attract the domestic and international investment needed to support entrepreneurs and expand economic opportunities. Frontier markets have a smaller scope and fewer institutional controls, and social relations and human behavior have a greater impact. Thus, the study of frontier capital markets provides a unique opportunity to examine the network-based intersection of human behavior and economics. The individual motivations, information availability, transaction systems, and cultural realities in these markets provide a rich context of study.

Capital Market Network Analysis

Network analysis can inform behavioral, financial, and development economists seeking to understand the essential characteristics that foster capital market development in countries where social capital can be as important as financial capital. As Stiglitz and Gallegati (2011) note, "Some network designs may be good at absorbing small shocks, when there can be systemic failure when confronted with a large enough shock. Similarly, some typologies may be more vulnerable to highly correlated shocks."[2] Goyal (2007) found that, "Network structure has significant effects on

---

[1] Levine, Ross and Sara Zervos (1996), "Stock Market Development and Long Run Growth," *World Bank Economic Review*, Vol. 10, No. 2.
[2] Stiglitz, Joseph E. and Mauro Gallegati, "Heterogeneous Interacting Agent Models for Understanding Monetary Economics," *Eastern Economic Journal*, Volume 37, Winter 2011, Bloomsburg, PA, Eastern Economic Association, p. 37.

individual behavior and on social welfare." He concluded that some networks are better than others to promote socially desirable outcomes, and both the quality and quantity of the links in the networks are important.[3]

This network approach is revealing existing qualities of market behavior that do not adhere to traditional economic assumptions contributing to the understanding of network science, economics, and capital markets. This social network analysis provides interesting insights about how interrelationships among actors, roles, and organizations affect market operations and development. Network analysis offers both a visual representation and a quantitative assessment of the relationships and information flows between people, organizations, and knowledge entities enabling classification of capital market structure and functions in innovative ways.

Functional Network Development

This research compares the capital market networks in three frontier markets – Ghana, Tanzania, and Trinidad and Tobago – to the capital market network in an emerging market – the Czech Republic. After collecting extensive résumé data about the actors in these markets, researchers used mathematical network analysis techniques to identify and evaluate the agents (or nodes) in each network. The initial focus was on stock exchange personnel and government regulators, but the networks expanded to encompass public companies, banks, brokers, and key personnel in government, the military, professional associations, and parastatal organizations. For each individual identified, the team recorded the organizations with which they were associated, including public and private firms, clubs and professional associations, as well as nationality, educational attainment, university affiliations, and teaching expertise. The team then used Organizational Risk Analyzer (ORA)[4] network analysis software to evaluate the data sets and develop social networks that describe the interrelationships among the individuals and organizations in the networks. Figure I shows a sample

---

[3] Goyal, Sanjeev (2007). <u>Connections: An Introduction to the Economics of Networks</u>, Princeton: Princeton University Press, pp. 54, 27.
[4] Carley, Kathleen M. (2001-2010). ORA: Organizational Risk Analyzer v.2.0.4. [Network Analysis Software]. Pittsburgh: Carnegie Mellon University.

agent-organization capital market network. The agents or individuals are represented by red nodes, the organizations by green nodes. This type of diagram may be useful for identifying key nodes in smaller datasets, but for datasets comprising hundreds of agents and organizations, its utility is somewhat limited.

Figure I: Sample Agent-Organization Network
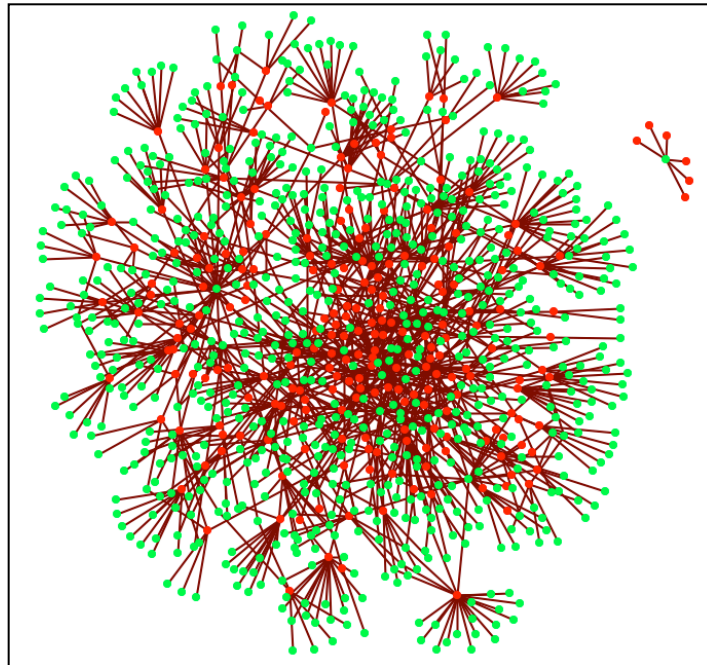
After developing the initial models for each capital market, the team conducted a network analysis and identified key people and organizations in each network. ORA generated myriad network metrics (such as density, characteristic path length, and betweenness and closeness centrality) on these initial networks highlighting which individuals and organizations were the most influential and interconnected. These networks allowed researchers to detect key actors and organizations for further research. Individuals and organizations high in certain centrality measures (such as degree centrality) were identified as important in the capital markets and targeted for on-the-ground interviews. For example, degree centrality is based on the idea that an agent is important or influential if the agent is linked to many other agents. (Centrality measures are discussed in more detail in the Results section.)

Research teams then conducted in-country research interviewing market participants and analysts to validate the initial network results and identify individuals and organizations to be included in subsequent network topologies. The interviews covered topics ranging from the development and operation of the stock exchanges to the banking and regulatory environment. [5] The team revised the initial capital market models based on information gleaned during the country visits. The most important nodes that were added to the models included key individuals at leading commercial banks, companies traded on the exchanges, trade association and industry group members, and large private companies (to the extent information was available). Researchers also expanded data collection efforts to include individuals and organizations noted as structural holes in the initial model.

The team once again used ORA network analysis software to evaluate the revised data sets and develop social networks that describe the interrelationships among the individuals and organizations in the networks. Using relational algebra and the capabilities of ORA, researchers also built networks to illustrate how individuals (agents) are connected through organizations and how organizations are connected to other organizations through individuals. These agent-agent and organization-organization networks proved useful in identifying key individuals and entities in each of the selected capital markets. However, the goal was to compare capital market networks (with different agents and organizations) at the macro level. Thus, researchers developed an innovative analytic framework that focused on the roles of individuals and organizations within the markets.

Researchers reviewed each individual's résumé data and assigned them up to three functions that best described their roles within the network based on both organizational affiliations and professional expertise. These functions encompassed both the types of organizations with which an individual was associated and the professional expertise individuals had attained. For example, lawyers, accountants and

---

[5] Evans, D. and Moten, M. *Lessons and Impressions of the Czech Capital Markets*, DTIC Technical Report 12-003, February 2012.

consultants were assigned the "professional services" function while a member of a trade union received the "association" function. Table I contains the list of functions assigned to individuals. Three roles were sufficient to cover the capital market participants studied.

Table I: Functions Listing

Agriculture	Government
Association	Healthcare
Banking	Industrial
Communications	Parastatal
Conglomerate	Professional Services
Consumer	Real Estate
Education	Tourism
Financial Services	Transportation

Once functions had been assigned, researchers used ORA to analyze the agent-function data sets. The resulting matrix depicted how people are connected to functions such as the matrix shown in Table II below. They transposed the Agent-Function matrix to create a Function-Agent matrix (Table III) and multiplied the matrices to obtain a Function-Function matrix (Table IV), which reveals how functions are related to other functions through individuals. In Table II, one sees that Agent Smith is linked to the banking and parastatal functions. These functions are linked in Table IV as indicated by the number 1 in the first row of the third column. Notice that in Table II, no agent is linked to both banking and consumer, so in Table IV, banking and consumer aren't linked, as indicated by the 0 in the first row of the second column.

Table II: Agent-Function Matrix

	Banking	Consumer	Parastatal
Smith	1	0	1
Jones	0	1	1
Miller	1	0	0

Table III: Function-Agent Matrix

	Smith	Jones	Miller
Banking	1	0	1
Consumer	0	1	0
Parastatal	1	1	0

Table IV: Function-Function Matrix

	Banking	Consumer	Parastatal
Banking	1	0	1
Consumer	0	1	1
Parastatal	1	1	1

The ORA-generated functional network topologies for Tanzania, Trinidad and Tobago, Ghana and the Czech Republic are depicted in Figures II - V. The node size was scaled based on the functions' row degree centrality, providing a visual representation of the functions that were most important in each capital market, potentially serving as central hubs and power brokers.
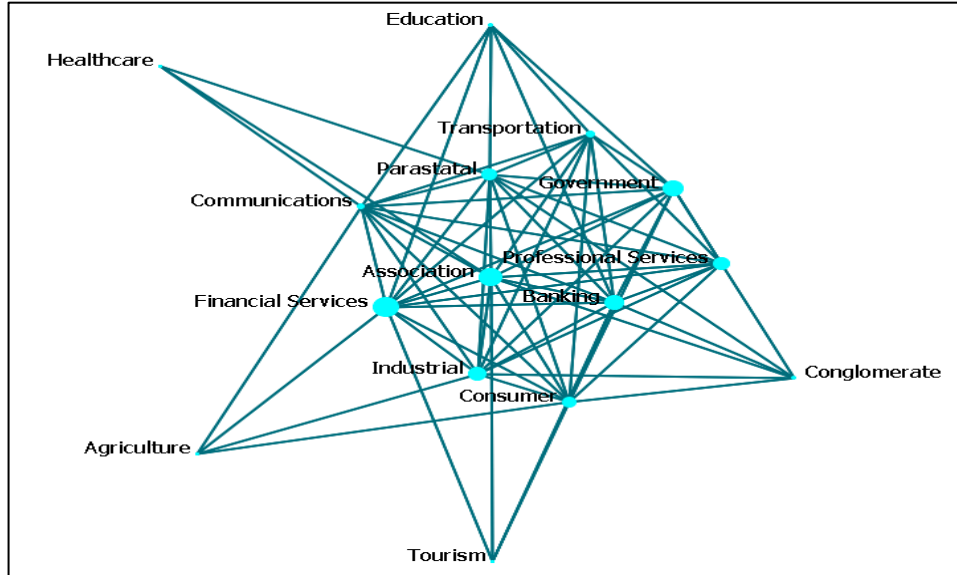
Figure II: Tanzania Functions Network

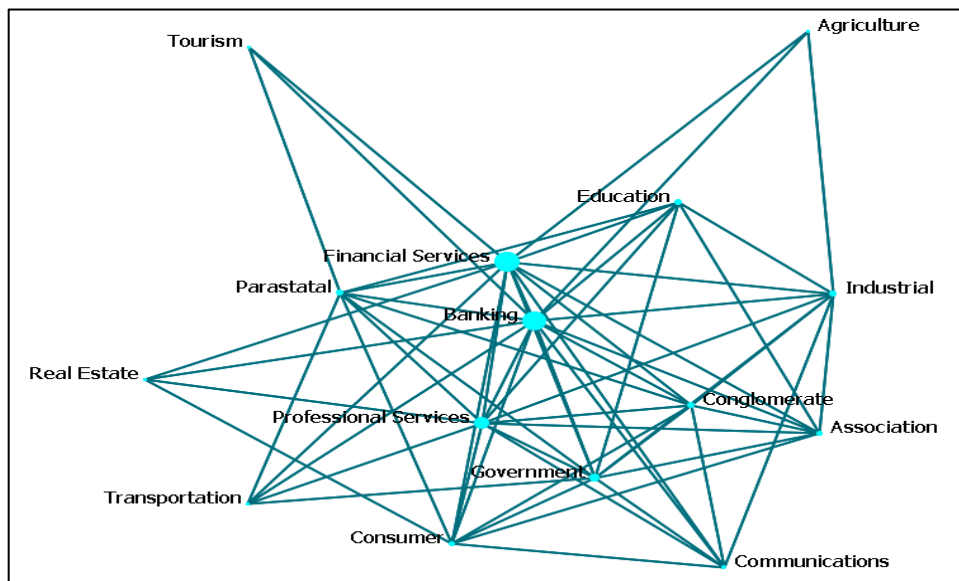## Figure III: Trinidad and Tobago Functions Network

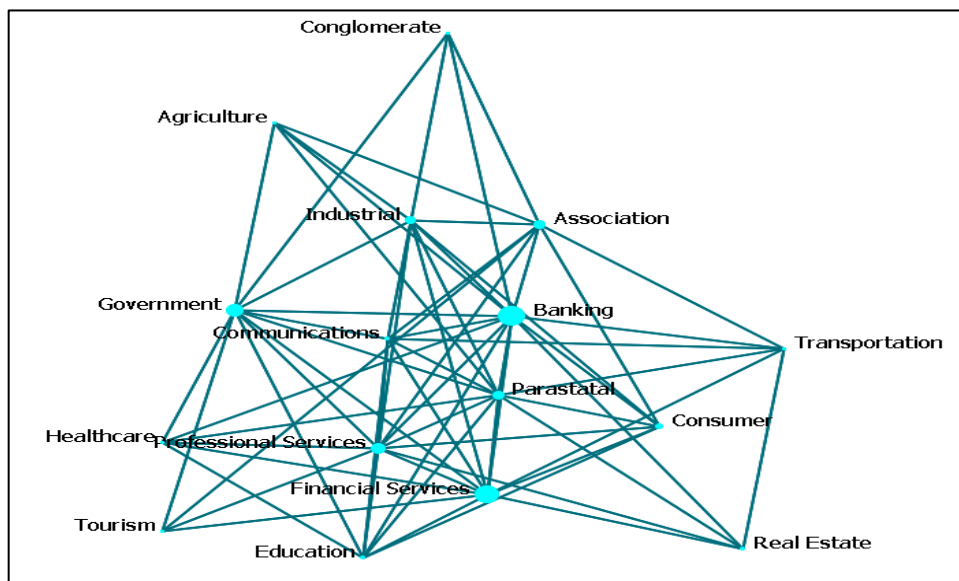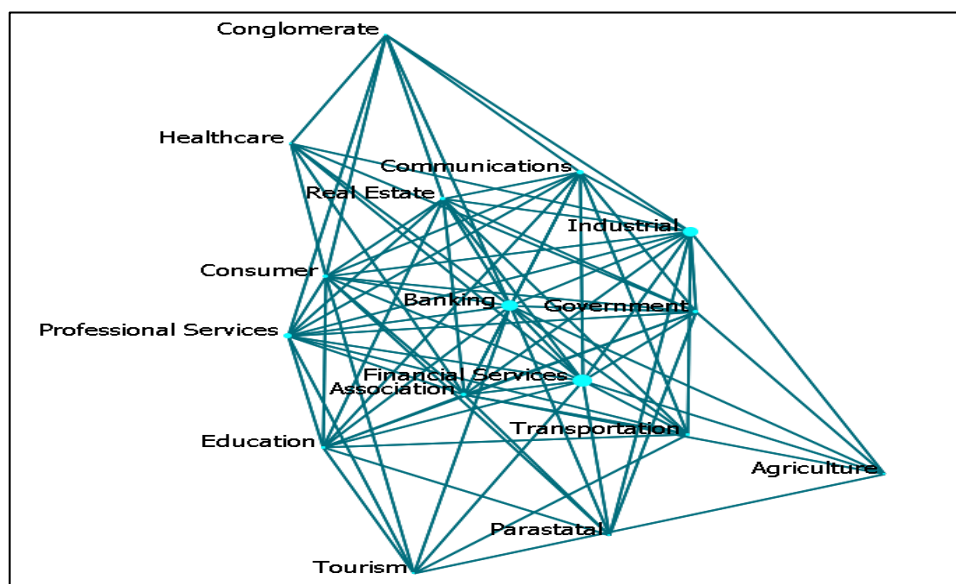## Figure IV: Ghana Functions Network

Figure V: Czech Republic Functions Network

Researchers then created a weighted network by assigning weights to each function in order to favor current roles over prior roles. Current functions were weighted twice as heavily as past functions. For example, an individual currently serving on the board of an oil company, who had formerly been a member of parliament would have two functions: industrial with a weight of two and government with a weighted of one. Using the same matrix algebra detailed previously, ORA generated weighted networks relating functions to other functions through people. This network analysis highlighted the functions that serve as central hubs and power brokers. It also identified potential points of failure, the nodes on the shortest paths between nodes that exhibit the most influence on other nodes, and the nodes on the periphery, lacking information or resources. These network topologies enable analysts to classify, compare and contrast capital market networks.

Results

Among the networks, Tanzania's financial market is the least developed of the four markets studied in terms of market capitalization, liquidity, trading volumes and technology. The different influences of each country's economic model and geographic

location have resulted in networks that exhibit different characteristics. Both Ghana and Tanzania continue to evolve from their African-socialist roots after independence from Great Britain in the 1960s. Both nations also implemented International Monetary Fund (IMF) structural adjustments in 1992 in which they liberalized their economies and created a multiparty system. Trinidad and Tobago, which gained its independence around the same time, adopted a British capitalist model. Trinidad's closeness to rich markets in North and South America and its economic links throughout the West Indies helped forge its economic path. Additionally, because Trinidad and Tobago is an island nation with close ties to its neighbors, it is more dependent on cross-border trade. Conversely, both Ghana and Tanzania originally established insular, self-supporting, centrally-planned economies. Although The Czech Republic has a more developed economy, it has more recently adopted capitalism and many vestiges of communist influence remain. Thus, differences in history, economic development models, and geography influenced each country's capital market network.

Tables V and VI provide summary statistics for each of the weighted functional networks calculated using ORA. (Detailed formulas and definitions may be found in *Social Network Analysis* by Wasserman and Faust [6] and in *Technical Report, CMU-ISR-11-107* by Carley, et. al.[7]) Node level measures (Table V) provide insights into the characteristics of individual nodes – their connectedness or lack of connections as well as their relative power and influence in a network. Network level measures (Table VI) afford researchers an opportunity to study the entire network and provide relevant statistics for comparing networks.

[6] Wasserman, S. and Faust, K. (1994), <u>Social Network Analysis: Methods and Applications</u>. Cambridge: Cambridge University Press.
[7] Carley, Kathleen & Reminga, Jeffrey & Storrick, Jon & Columbus, Dave. (2011). ORA User's Guide 2011. *Carnegie Mellon University, School of Computer Science, Institute for Software Research, Technical Report, CMU-ISR-11-107.*

Table V: Comparative Node Level Statistics

Measure	Ghana	Trinidad and Tobago	Tanzania	Czech Republic
Average Total Degree Centrality	0.0950	0.0790	0.1150	0.0650
Average Eigenvector Centrality	0.2580	0.2700	0.2980	0.2600
Average Closeness Centrality	0.1900	0.1390	0.2630	0.2090
Average Betweenness Centrality	0.0860	0.0840	0.0590	0.0910
Clique Membership Count	5.3750	4.4670	2.5330	5.5630
Simmelian Ties	0.5580	0.5900	0.6480	0.7000
Clustering Coefficient	0.7120	0.8200	0.8560	0.7900

Figure VI graphically depicts node level comparative measures for several centrality indications. These measures attempt to quantify how influential (or central) a function is within each network based on different types of affiliation. For example, degree centrality measures how connected a function is to other functions. Functions high in degree centrality are linked to many other functions and may exert influence on those functions with which they are linked. Our analysis revealed that, on average, nodes in Tanzania's network exhibited the highest degree centrality – 1.76 times higher than the Czech Republic's network (which had the lowest average degree centrality) and 1.46 times higher than Trinidad and Tobago's network. These measures suggest that in Tanzania, agents have more links to other functions than agents in the other countries.

Another way to evaluate power relationships in a network is through closeness centrality, which measures how near each function is to other functions in the network. Functions high in closeness centrality may indirectly influence other functions. Among our networks, Tanzania exhibited the highest closeness centrality followed by the Czech Republic, while Trinidad's network exhibited the lowest. Thus, the functions in Tanzania are more closely connected indicating that some functions may have more indirect power than their counterparts in the other countries.

Figure VI: Average Node Level Centrality Measures by Country
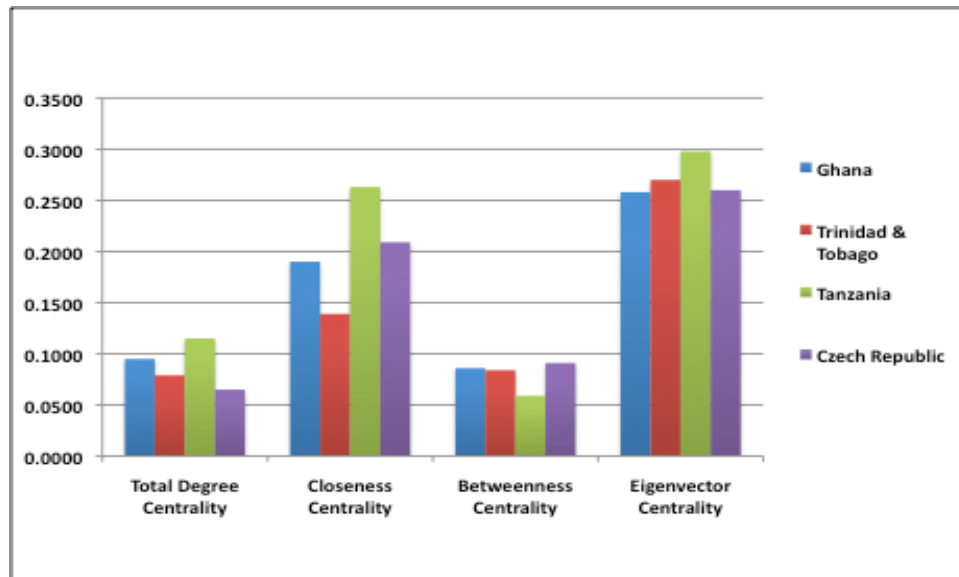
The concept of betweenness centrality quantifies influence based on a function's position on the path between other functions. Functions high in betweenness centrality can be bridges that share information or obstacles that prohibit access to information. Our comparison revealed little difference among the networks, with the exception of Tanzania. Functions in the other networks exhibited approximately 1.5 times the levels of betweenness centrality as Tanzania's network, indicating that fewer functions serve to share or withhold information in its network. A more nuanced approach to understanding influence in a network is through the metric eigenvector centrality. A function that is connected to other highly connected functions will exhibit high levels of eigenvector centrality, and thus, be expected to exert influence through these connections to powerful functions. Once again, Tanzania's functions network exhibited the highest levels based on this centrality measure (between 10% and 15% higher), while the other networks were largely similar.

Networks can also be evaluated by analyzing the quantity and composition of subgroups within the network. Table V provides a comparison of two measures to

evaluate these groups – clique membership count and clustering coefficient. A clique is a group of three or more nodes (in this analysis functions) that are directly connected to all the other nodes (functions) in the group. Tallying the number of distinct cliques to which each function belongs produces a function's clique membership count. Tanzania's network was once again quite different than the other networks based on this metric with a clique membership count less than half that of the Czech Republic's network. Thus, functions in Tanzania may be more distinct from other functions. Watts and Strogatz[8] developed a metric to identify clusters within a network, the clustering coefficient, which measures the cliquishness of a typical friendship circle in the network (the percentage of a node's friends that are also friends of each other). In the functions networks we studied, Tanzania's had the highest clustering coefficient – 1.2 times Ghana's and 1.1 times the Czech Republic's. In Tanzania, friendship ties may be more important to successfully navigate through its capital market network.

Table VI: Comparative Network Level Statistics

Network Level Measures	Ghana	Trinidad and Tobago	Tanzania	Czech Republic
Row and column count	16	15	15	16
Link count	67	62	68	84
Density	0.5580	0.5900	0.6480	0.7000
Characteristic path length	5.4670	7.3520	7.8000	4.9250
Network Diameter	10	15	14	10
Degree centralization	0.2450	0.2090	0.1710	0.1680
Betweenness centralization	0.2790	0.1520	0.3020	0.2500
Closeness centralization	0.1610	0.0750	0.2230	0.1400
Eigenvector centralization	0.5780	0.6010	0.3780	0.6190

Table VI provides network level comparisons of the four countries. The row and column counts are slightly smaller in Tanzania and Trinidad because one function in each country was not associated with any individual. In Tanzania, no agents were involved in real estate; in Trinidad, no agents were associated with healthcare. The

---

[8] Watts, Duncan J. and Steven H. Strogatz, "Collective Dynamics of 'small-world' networks," Nature, Vol. 393, June 1998, p. 440 – 442.

Czech Republic's network had the highest number of links between the functions – between 24% and 35% more than the other networks. Density measures the percent of actual links to possible links in a network. Higher density is associated with greater information sharing which is characteristic of learning organizations. The Czech Republic's network was the most dense at 70% versus Ghana's 56%, Trinidad's 59%, and Tanzania's 65%. Both Tanzania and Trinidad had significantly longer path lengths. Network diameter reflects the longest distance between any two functions. Accordingly, Trinidad and Tanzania's networks had the greatest diameter, 15 and 14, respectively, vs. 10 in the other networks. These measures suggest that information flows less directly, and possibly less efficiently, in the Tanzania and Trinidad functions networks.

Figure VII provides comparative network level centralization measures for each country's capital market. Degree centralization can be used to evaluate whether a network is in danger of splitting apart if nodes are removed from the network. A network that exhibits low degree centralization is one in which the network remains highly connected even if a node is removed. All of the networks we studied showed low degree centralization suggesting that no single node or group of nodes is particularly dominant in the networks; however, Ghana's network registered a value 46% higher than the Czech Republic's network. Ghana's relatively higher degree centralization suggests that its network is more susceptible to fragmentation than the other networks and that a few nodes have higher degree centrality than the other nodes.

Betweenness centralization measures whether a network has few or many functions that lie between other functions in the network. Networks with higher betweenness centralization have more intermediaries or bridges connecting disconnected groups. Closeness centralization measures the proximity of functions to other functions in the network. For each of these measures, Tanzania registered significantly higher values than did Trinidad. Tanzania's betweenness centralization was almost twice that of Trinidad, indicating fewer groups were disconnected.

Figure VII: Network Level Centralization Measures by Country
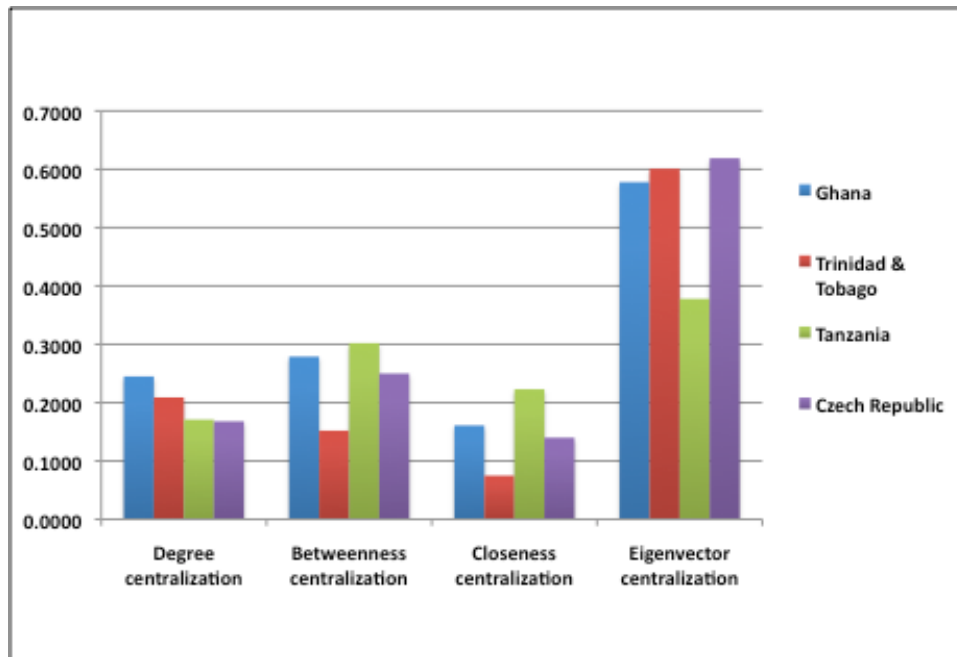
Tanzania's closeness centralization was almost three times Trinidad's, and about twice that of the other networks, suggesting that information flows are centralized around single agents or groups in Tanzania. Eigenvector centralization, which measures the connectedness of functions to highly connected functions, was significantly lower in Tanzania (between 35% - 39% lower than the other networks). Taken together, these centralization measures reveal a disparity among the networks. Tanzania's network has more functions that serve as gatekeepers or bridges that can broker information; however, not as many of these functions are connected to other highly connected functions. Thus, although there are more of these brokering functions in Tanzania, they are not necessarily that influential.

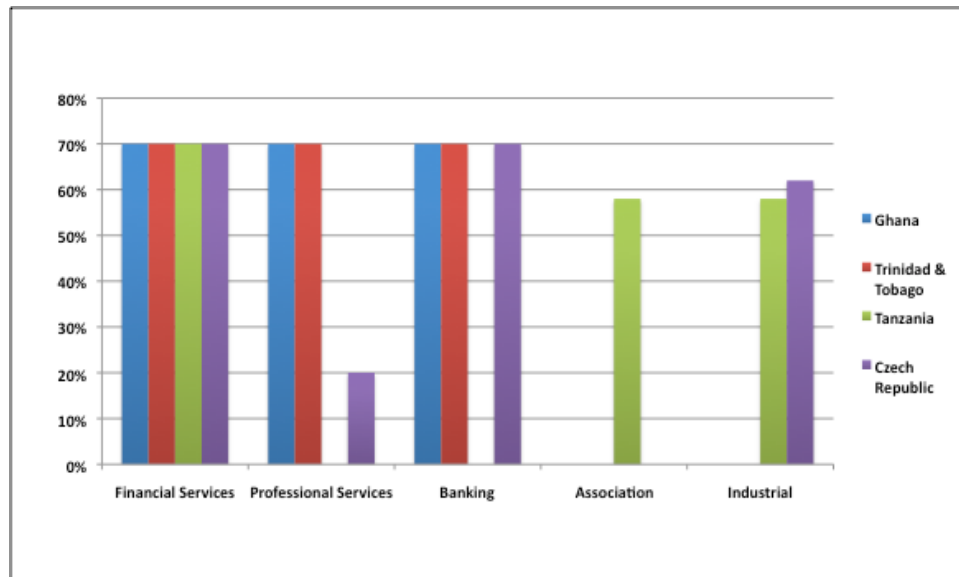**Figure VIII: Most Prominent Functions Comparison**

Figure VIII highlights the most prominent functions or key nodes in each of the networks based on ORA's summary of centrality measures (which counts the number of times a function is in the top ten in a centrality measure). The top three nodes for Ghana and Trinidad were identical in the networks with financial services (such as broker dealers and asset managers), professional services (including attorneys and accountants) and banking, each recurring in 70% of ORA indications. Financial services and banking were equally prominent in the Czech Republic, but professional services were much less so (recurring in only 20% of ORA indications). The industrial role was also very important in the Czech Republic, which is logical based on the country's communist past and the relatively recent privatization of many of its formerly government-owned heavy industries. In Tanzania, financial services was as important as in the other capital markets; however, banking was not prominent while the association and industrial functions each had a 58% rate of recurrence. As the government in Tanzania was quite robust before the IMF adjustments, many of its central actors remained connected in the political, economic, and government spheres after liberalization. In contrast, Ghana's pre-liberalization government was much

weaker, which may account for the fact that associations and government ministries exert less influence in Ghana's financial system.

Figure IX identifies the functions that exhibited the highest eigenvector centrality in each network. In this context, eigenvector centrality measures the functions that are most connected to other highly connected functions. In all the networks, financial services and professional services were very important functions; however, banking was extremely important in the Czech Republic, Ghana and Trinidad and Tobago but not as prominent in Tanzania. The minor role of banking in Tanzania is likely due to the timing of deregulation; Ghana began deregulating its banking sector in the mid 1980s, while Tanzania did not initiate a similar program until the 1990s. The government and parastatal roles were less important in the Czech Republic and Trinidad than in the African countries. In contrast, Czech and Tanzanian associations and industrial organizations exhibited high eigenvector centrality indicating the manufacturing base is still quite important in Tanzania's capital market network. Interestingly, real estate firms were influential in the Czech Republic. This result may be due to the larger number of listed firms on the Prague stock exchange and the greater information available about non-public companies operating in the Czech Republic.

Figure IX: Eigenvector Centrality Comparison
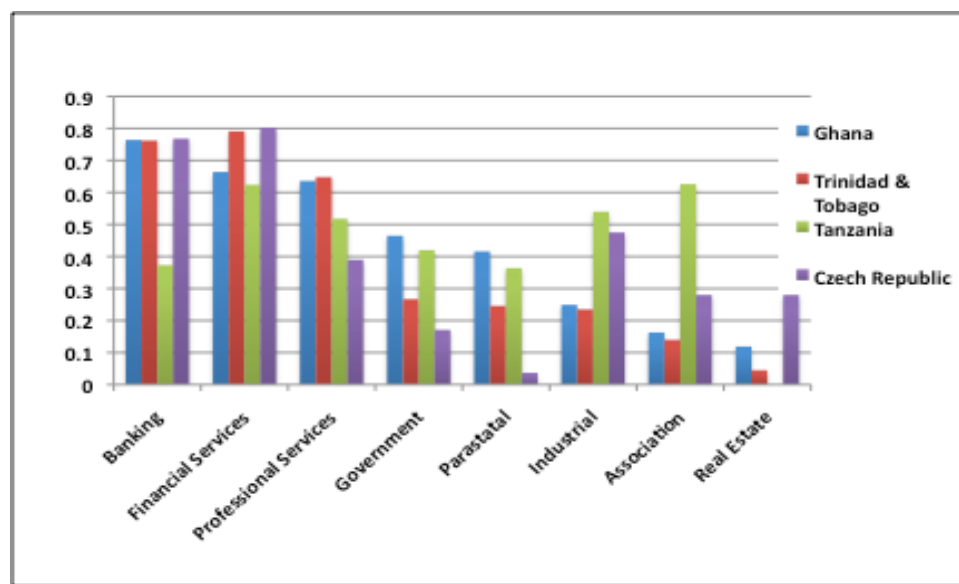
Closeness centrality measures the average proximity of a function to other functions in the network. Nodes high in closeness centrality are considered hubs and efficient communicators. Figure X identifies the functions that exhibited the highest closeness centrality in each network. As indicated, limited differentiation existed among the networks. One point of interest is the fact that in Trinidad and Tobago, all of the closeness centrality values were lower, especially relative to Tanzania, possibly indicating a higher level of functional specialization in Trinidad and Tobago's more developed capital market. One might have predicted that in the island nation of Trinidad and Tobago, tourism would have been a played a more central role. The communications function was most important in Tanzania based on closeness centrality, but transportation, education, banking and parastatal roles were prominent as well. The range of closeness centrality values in the Czech network was small, with professional services, education, consumer, and parastatal functions slightly higher than the other functions. Trinidad and the Czech Republic were expected to have more similar networks, given they are considered to be more developed than the African markets; however, this did not prove to be the case.

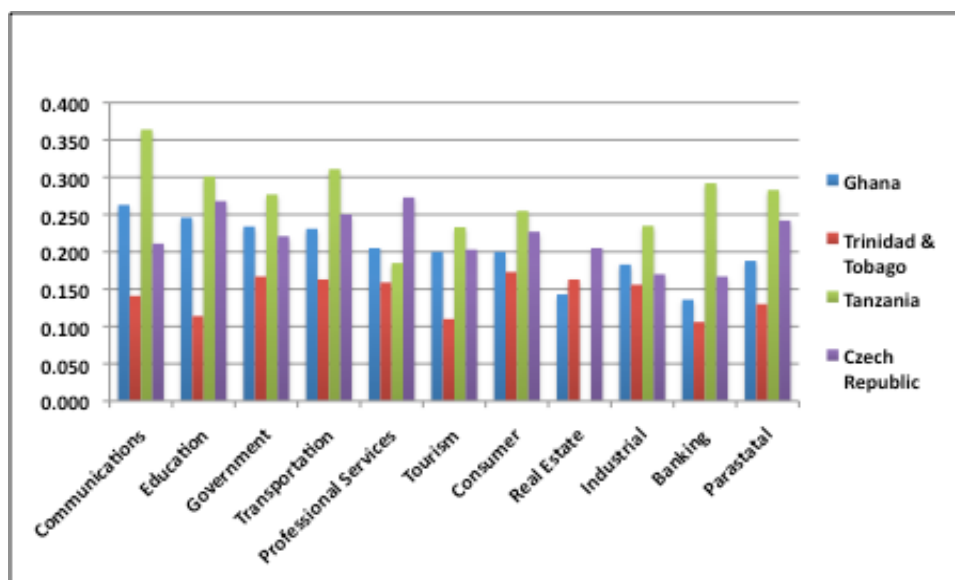**Figure X: Closeness Centrality Comparison**

Figure XI reveals stark differences between the networks in terms of betweenness centrality. Nodes high in betweenness centrality are often considered power brokers that bridge the gap between connected and unconnected nodes. Of particular interest is that the financial services function exhibited low betweenness centrality in all the capital market networks studied. The agents who served in the communications role served as liaisons or gateways in Ghana and Tanzania, which seems appropriate in evolving markets where Internet connectivity and phone service are game changers. Individuals in industrial roles in Trinidad and Tobago and education roles in Ghana and the Czech Republic were also influential. Government and tourism were bridging functions in Ghana. The most important power brokering functions in the Czech Republic were parastatal organizations, followed by education, consumer and transportation. However, only those agents with transportation roles were influencers in all four countries.

Figure XI: Betweenness Centrality Comparison
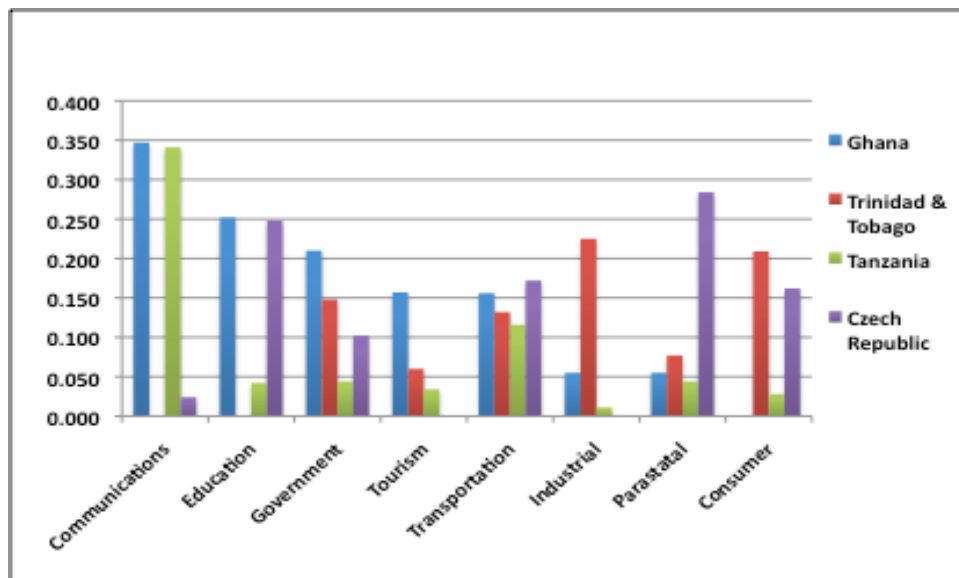
LIMITATIONS

Collecting data in these markets proved challenging. Information availability varied widely among the entities examined. Some websites provided extensive biographies for their executives, while others listed very little or nothing at all. Some individuals may appear to be extremely influential relative to their peers because they have chosen to publish extensive background information. Conversely, influential individuals may prefer to remain anonymous posting little personal information on the Internet. Consequently, the networks may contain structural holes if an undocumented relationship existed among individuals or organizations, due to either errors of omission or commission.

Also, many firms may not update their websites frequently, requiring additional assessments to validate individual résumé data. However, the network may still be incomplete if an individual has become a member of another board, completed a university degree, or joined a professional organization since his or her résumé was posted. Data collection is further complicated by the difficulty of keeping the dataset up to date. Short of developing a web crawler or checking corporate Internet sites regularly, it is difficult to know when a key person changes institutions or a new individual joins a key organization. It is quite possible that by the time this research is completed, the network topologies will have lost a significant level of their accuracy in reflecting the capital markets. As a result, these static models are not very sensitive to changes among the economic actors and entities within the capital market.

Perhaps the greatest limitation in the network arises from a key assumption: if two people are associated with an organization or institution, they have a significant link or connection. In reality, this simplifying assumption causes the model to overstate some relationships. For example, the capital market network shows links between two people who went to the same university; however, universities are large organizations and student ages and fields of study vary such that two individuals attending the same university may never have met. Likewise, individuals may have worked for the same organization or served on boards of directors at different times making it difficult to know if an actual link exists between them. As a result of these limitations, our model may

overstate the number of links among individuals and organizations or fail to recognize links that may exist. Despite these limitations, however, this methodology provides a unique framework for understanding capital market network topologies, functions, and power relationships.

CONCLUSIONS

This capital market network research generated functional network topologies and statistics for three frontier capital markets and one emerging market. We identified similarities and differences in the capital market networks using three different centrality measures as a technique to compare and contrast capital markets. This research produced a unique, quantitative methodology for classifying capital markets.

Among the networks, Tanzania's financial market is the least developed of the four markets. From a network analysis perspective, Tanzania's network was distinct from the other networks with the highest average degree, closeness, and eigenvector centrality and the lowest average betweenness centrality. These measures suggest that in Tanzania's network, functions are more interconnected and more functions exert indirect influence on other functions. Tanzania's market is characterized by more functions that serve as bridges that can broker information and connect disconnected functions, and more functions that may influence other functions through their connections to powerful functions. Furthermore, Tanzania's network contained fewer cliques and was more highly clustered, indicating that functions in its network were more distinct and that friendship ties are important to successfully navigate Tanzania's financial system. In-country research confirmed this assessment.

All of the functions networks had densities ranging from 56% to 70%; thus, the network topologies are more lattice than star shaped. However, the Czech Republic's network had the most links among its functions and was the densest, suggesting that power is more concentrated in certain functions in its capital markets. The Czech Republic and Ghana also had shorter path lengths and smaller network diameters indicating information flows more directly and possibly efficiently through their networks.

In order to distinguish the quantitative difference between these four networks, analysis focused on those top ten functions that are distinctively different in each capital market's functions network topology. As would be predicted in a study of capital markets, the key function in each of the networks was financial services. In the Czech Republic, Ghana and Trinidad, banking was equally important. Banking was not a prominent function in Tanzania; however, associations and industrial functions were prominent. Interestingly, industrial was a very prominent function in the Czech Republic as well.

Differences in results based on the selected metric can potentially lead to the discovery of influential functions that might not be readily apparent at first observation or conversely, might not appear to be as influential as initially supposed. In this analysis, different functions emerged as important depending on the centrality measure selected. Trinidad's closeness centrality measures were much lower than the other networks possibly indicating a higher level of functional specialization in its capital market. Interestingly, the financial services, professional services, and banking functions exhibited very low levels of betweenness centrality, while communications emerged as the most important function in both Ghana and Tanzania confirming the importance of the Internet and phone infrastructure in evolving economies. In the Czech Republic, parastatal and education roles were key power brokers.

When considering those functions that are connected to other highly connected functions (eigenvector centrality), Tanzania's associations and industrial organizations featured prominently. Tanzania's economy may be still be influenced by its manufacturing base and powerful trade unions. In the Czech Republic, the financial services and banking functions were the most connected to other powerful functions, but industrial and professional services functions were also well connected.

This comparison reveals similarities and differences in the network structures of developing versus emerging markets furthering an understanding of the types of social networks that have fostered economic growth. These models offer insights to economists seeking to understand the interconnections between economic actors and their affects on financial markets and economic conditions. This research also informs

governmental and nongovernmental organizations that are creating economic development policies, enabling decision-makers to focus on aspects of the network that will generate results efficiently. For example, Tanzania's capital markets may evolve more quickly if it can reduce the influence of associations and friendship ties.